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## Spray-coated $\text{Cu}_2\text{ZnSnS}_4$ thin films for large-scale photovoltaic applications

Sara Engberg<sup>\*1</sup>, Swathi Murthy<sup>2</sup>, Simón López Mariño<sup>3</sup>, Ole Hansen<sup>3</sup>, Guggi Kofod<sup>2</sup>, and Jørgen Schou<sup>1</sup>

1: DTU Fotonik, 2: Inmold, 3: DTU Nanotech.

\*Corresponding author email: [sleen@fotonik.dtu.dk](mailto:sleen@fotonik.dtu.dk)

The kesterite material,  $\text{Cu}_2\text{ZnSnS}_4$  (CZTS), has in the preceding ten years been investigated and developed as a new Earth-abundant material for solar cells. The interest in this inorganic semiconductor originates in its optimal energy band gap of approx. 1.5 eV, high absorption coefficient, and the high material abundance and low toxicity of all elements included. The current challenges are related to unavoidable antisite disordering stemming from the chemical similarity of the cations, which causes bulk defects and lowers the open-circuit voltage detrimentally. This, however, did not restrict the “cousin”-material,  $\text{CuInGaSe}_2$  (CIGS), which is currently one of the main thin-film photovoltaic (PV) technologies on the market.

In this work, CZTS thin films have been fabricated by solution-processing, which allows relatively fast and inexpensive deposition when compared to vacuum-processed films. The nanoparticles are synthesized by the hot-injection method by mixing targeted ratios of metal salts with sulfur in diethylene glycol, resulting in a phase-pure CZTS material [1]. Inks are formulated by dispersing the particles in ethanol and water using a suitable dispersing agent. The solvents used allow that alkali metal chloride salts can also be dissolved in controllable amounts, which we have found enhances grain growth in the films during the subsequent annealing step.

A Sono-tek spray-coating system with ultrasonic atomization is used. We investigate the effect of ink concentration, and spray-coating conditions, including spray power, flow rate from syringe pump, and time between consecutive spray layers. The films are annealed in a tube furnace, and to avoid decomposing the material into secondary phases, a graphite box is used to enable an overpressure of sulfur and tin-sulfide. The annealed, spray-coated films are characterized by scanning electron microscopy (SEM), optical microscopy, and Dektak profilometry.

[1] Naghmeh Mirbagheri, Sara Engberg, Andrea Crovetto, Søren Simonsen, Ole Hansen, Yeng Ming Lam, and Jørgen Schou, *Synthesis of ligand-free CZTS nanoparticles via a facile hot injection route*, Nanotechnology, 27 (2016).